

Weak-field ELF magnetic interactions: Implications for biological change during paleomagnetic reversals

Abraham R. Liboff

Department of Physics, Oakland University, Rochester Hills, MI, USA

Contrary to the belief that paleomagnetic reversals are not biologically significant, we find good reason to think otherwise. Attention is drawn to polarity transitions, time intervals a few thousand years long that follow the collapse of the existing geomagnetic dipole moment and precede the establishment of the new, oppositely directed moment. The geomagnetic field during transitions is reduced to a maximal mean intensity about 10% of the stable field and can exhibit low-frequency perturbations comparable to numerous laboratory-based extremely low frequency (ELF) studies reporting biological interactions, making it very likely that similar interactions must occur over the course of a polarity transition. This conclusion is strengthened by reports of medical problems that significantly correlate with intense solar winds, events that also generate ELF perturbations similar to those that can occur during polarity transitions.

Keywords: ELF biomagnetic effects, geomagnetic perturbations, GMF diurnal rhythm, polarity transitions, solar wind bioeffect

Introduction

The possibility of significant biological effects due to paleomagnetic reversals is generally discounted, mainly because the magnetic intensities involved appear to be too weak to be of consequence, an assumption seemingly borne out by the sparse evidence for such a connection. Except for rare instances in the fossil record (Crain, 1971; Hays, 1971), there is no indication that these reversals have played even a minor role in evolutionary expression. Further, even apart from the apparently inconsequential size of the earth's magnetic moment, birds and other organisms dependent on the geomagnetic field (GMF) for navigation are not likely to be affected by reversals of the earth's magnetic moment if they make use of an inclination compass (Wiltschko & Wiltschko, 1972). In the following we dispute this long-held view, arguing that there are sound reasons to expect robust effects in biological organisms during the polarity transition of the reversal process. This transition (here labeled interchron) lasts on the order of a few thousand years (Clement, 2004) following the collapse of the earlier magnetic moment and prior to the establishment of the new oppositely directed moment. The GMF during this

Correspondence: Abraham R. Liboff, Department of Physics, Oakland University, Rochester Hills, MI, USA. Tel.: 561 495 0970. E-mail: arliboff@aol.com

Received 27 August 2012; revised 7 October 2012; accepted 11 October 2012

period is highly unstable with a mean maximal intensity about 10% of that of the stable chron. Despite the lack of specific data to directly support the thesis that interchrons are biologically significant, there is strong circumstantial evidence that the type of weakly intense magnetic field changes putatively associated with such transitions has elsewhere been implicated in a wide variety of biological effects (Greenebaum & Barnes, 2006).

Cosmic radiation

This question is complicated by the increase in ground-level cosmic ray intensity that accompanies periods of reduced GMF intensity. The geomagnetic dipole acts as a brake on local cosmic ray activity. This is evidenced by the latitude effect (Compton, 1933) in which the maximum cosmic ray intensity is observed at the poles of the earth, where the Lorentz force is least. Alterations in this activity are also readily associated with geomagnetic perturbations due to solar wind interactions with the magnetosphere of the earth, as evidenced by both Forbush decreases (Cane, 2000) and the inverse correlation between cosmic radiation and the 11-year solar cycle. Therefore, one can safely assume that the cosmic ray flux at the ground level is greatly increased during GMF polarity transitions. No direct experimental evidence links enhanced cosmic ray intensity to specific biological effects but it is not unreasonable to think that this is likely. A rough measure of cosmic ray ionization resulting from a collapsed GMF is obtained by comparing the ionization density, in ion pairs/cm³/s at the Pfotzer maximum (the height in the atmosphere where maximum cosmic ray ionization occurs; Singer, 1950) to that at sea level (Kyker & Liboff, 1978). This amounts to a relative change of $\sim 260/2.15 = 120$ -fold, an increase in the radiation dose rate from cosmic rays from 0.32 mSv/year to approximately 40 mSv/year, well in excess of the International Commission on Radiological Protection (ICRP) radiation protection limit (Wrixon, 2008).

This increased cosmic ray burden is only a fraction of the effects on living things that can be expected due to a sharply reduced geomagnetic intensity. Of particular concern are the highly energetic particles generated outside of our solar system and even outside of our galaxy which are normally deflected away from the earth by the GMF.

Weak ELF biointeractions

A second way of producing biological change, above and beyond that due to cosmic radiation, is also expected during polarity transitions. There is substantial evidence that biological effects can arise from nonionizing low-frequency electromagnetic exposures, in some cases at levels similar to the GMF perturbations associated with both solar wind interactions and reasonable estimates of the interchron field. This evidence is laboratory based, and therefore independent of being confused with effects that might be the result of cosmic rays. Despite their sound experimental basis, these interactions with living systems remain poorly understood, mainly because the magnetic field effects in question are due to intensities too weak to be considered the result of either Faraday induction or Joule heating. Nevertheless, the experimental record suggests that GMF changes akin to those occurring during polarity transitions can be expected to affect biological systems in a manner very different from that related to increased cosmic ray ionization intensity. Instead of effects related either to the reduction in the GMF or its reversal, these changes will occur as a direct result of the extremely low frequency (ELF) character of the interchron magnetic field.

In these reports magnetic fields on the order of a few microTesla at frequencies within the 3–300 Hz ELF range have been shown to affect the physiological state in a wide variety of biological model systems. Examples of these include changes in DNA synthesis (Liboff, Williams, Strong, & Wistar, 1984), diatom motility (Smith, McLeod, Liboff, & Cooksey, 1987), mitogenic response in lymphocytes (Cossarizza et al., 1989), recruitment of glycosaminoglycans (Smith, McLeod, & Liboff, 1991), growth rate of cancer cells (Liburdy, Sloma, Sokolic, & Yaswen, 1993), planarian regeneration (Jenrow, Smith, & Liboff, 1995), expression of insulin-like growth factor (Fitzsimmons, Ryaby, Magee, & Baylink, 1995), opioid analgesia in snails (Prato, Kavaliers, & Carson, 1996), rat behavior (Zhadin, Deryugina, & Pisachenko, 1999) and plant growth (Galland & Pazur, 2005). The unusually varied nature of this list serves to reinforce the fact that these reports are not mere epiphenomena, but rather strong evidence of a fundamental robust response to weakly intense ELF magnetic fields. A notable recent addition to these reports is the ability of 2.5 μT ELF magnetic fields to enhance differentiation of cardiac stem cells for application as cell therapy in heart failure (Gaetini et al., 2009). This array of reports implicating weakly intense magnetic fields in biological expression is even more credible if one includes the fact that animal magnetosensitivities for purposes of orientation, as in pigeons and honeybees, are found for intensities also extending well below 5 μT (Wiltschko & Wiltschko, 1985).

This puzzling magnetic effect, first reported by Adey (Bawin, Adey, & Sabbot, 1978; Bawin, Kazmarek, & Adey, 1975), and subsequently elaborated by others (Blackman, Benane, Kinney, Joines, & House, 1982; Dutta, Ghosh, & Blackman, 1989; Dutta, Subramoniam, Ghosh, & Parshard, 1984; Schwartz, House, & Mealing, 1990) was later found to involve the physical domain as well. In 1998, a group led by Zhadin extended this work to much weaker magnetic fields, discovering that intensities as low as 40 nT can sharply shift the electrical conductivity of polar amino acids in aqueous solution (Zhadin, Novikov, Barnes, & Pergola, 1998). This result, since replicated elsewhere (Alberto et al., 2008; Commisso et al., 2006; Pazur, 2004), has been tentatively explained (Del Giudice, Fleischmann, Preparata, & Talpo, 2002) in terms of a quantum electrodynamic interaction that reduces the viscosity of water to the degree where enhanced Lorentz force effects are observed on solvated ions at room temperature. Whatever the explanation, there emerges from all of this the fact that biological systems are extraordinarily sensitive to very weak magnetic fields, whether static or as perturbations to the magnetostatic case.

Additional evidence reinforcing this conclusion comes from observations on the effects of weak magnetic fields on free radical recombination rates (Timmel, Till, Brocklehurst, McLauchlan, & Hore, 1998). Of particular significance in this regard is the influence of such fields on reactions involving cryptochrome, a protein intimately involved in the regulation of the biological clock (Close, 2012). The damaging consequences of chronodisruption are increasingly implicated in the initiation of human illness (Lopez, private communication; Erren et al., 2008).

It is interesting to note that the weakly intense low-frequency character of these magnetic fields corresponds closely to a number of geophysical phenomena, other than interchons. Pertinent low-frequency disturbances in the GMF include its diurnal variation (50 nT) (Okeke & Hamano, 2000), transients during Pc 1 oscillations (tens of nT) (Kaye & Kivelson, 1979), and solar wind effects following coronal mass ejections (hundreds of nT) (Love, 2008).

There is substantial evidence showing that humans are affected by solar activity (Close, 2012), with increases in cardiovascular events (Corenellisen et al., 2002) and suicides (Berk, Dodd, & Henry, 2006) correlated with solar wind interactions with the magnetosphere. The physiological pathway explaining such effects remains obscure,

but it is difficult to ignore these correlations, especially if they are seen as an adjunct to the more directly obtained experimental data implicating weak-field low-frequency magnetic fields interactions with living things.

The interchron field

In view of the relatively short lifetimes of polarity transition events, it is difficult to precisely determine their magnetic characteristics. Although magnetometer readings on sedimentary rocks and ocean bottoms can distinguish reversals in the GMF dipole that happen every million years or so, it is far more problematic to discern magnetic changes during the interchron itself, because sedimentation rates are too small to provide enough sample thickness corresponding to merely a few thousand years. The sedimentary interval occurring during a polarity transition is typically represented by merely a few centimeters of sediment. For example, in one of the few studies on interchrons *per se*, it was found (Clement, 2004) that they lasted as little as 1800 years and as long as 11 800 years with an average lifetime of about 7000 years.

During this time the GMF is not only sharply reduced in intensity, to levels of $5\ \mu\text{T}$ and less, but is also highly unstable, reflecting the inability of the geodynamo to generate a coherent dipole moment. This results in a rapidly changing field as well as one that is represented globally by quadrupole and octupole moments replacing the usual dipole field. It seems clear that this chaotic situation will generate a wide band of magnetic frequencies. Pending a more complete understanding of the processes within the outer core of the earth, the precise details of this frequency distribution are unknown. Nevertheless, it is very likely that these chaotic conditions will result in frequency contributions that include those in the ELF range. These geomagnetic perturbations, similar to those stemming from solar wind interactions at the magnetosphere, have a high-frequency cut-off due to the earth's electrical conductivity. One can reasonably anticipate therefore that ELF magnetic fields must necessarily accompany polarity transitions, and with these, the strong likelihood of resulting biological change.

Conclusion

We find good reason to expect biological effects connected to geomagnetic reversals. Above and beyond effects directly related to increased cosmic ray ionization, there must also be considered separate additional biological responses due to weakly intense ELF magnetic fields generated during the polarity transitions.

Although the magnetically related biological effects due to polarity transitions can in some regards be thought of as similar to those following solar storms, there is one important difference. Geomagnetic effects related to solar storms are measured in terms of days while those derived from interchrons are measured in terms of thousands of years. It seems reasonable to assume that whatever somatic and genetic effects that are presently related to solar activity will be enormously amplified due to the much larger temporal extent of the magnetic reversal process. In short, the biologically interactive nature of ELF magnetic fields makes it difficult not to conclude that there are consequent effects on living things due to the conditions that are present during the thousands of years of continued magnetic instability in a typical polarity transition.

We also bring to the reader's attention that there appears to be a geophysical commonality involving weak ELF magnetic field effects, spanning

those due to GMF diurnal rhythms, Pc 1 oscillations, solar activity and polarity transitions. The multi-billion-year exposure to these geomagnetic perturbations over the course of evolution suggests a heretofore unsuspected naturally occurring environmental link to explain why living things are sensitive to ELF magnetic fields.

Acknowledgements

The author is indebted to I. Y. Belyaev for first raising the question with him about possible biological effects during geomagnetic reversals. The author also thanks J. J. Love for a helpful discussion concerning the geomagnetic effects of solar activity, and F Barnes for his suggestions concerning the role of free radical recombination rates in ELF phenomena.

Declaration of interest

The author reports no conflicts of interest. The author alone is responsible for the content and writing of the paper.

References

- Alberto D, Busso L, Crotti G, Gandini M, Garfagnini R, Giudici P, Gnesi I, et al. (2008). Effects of static and low-frequency alternating magnetic fields on the ionic electrolytic currents of glutamic acid aqueous solutions. *Electromagn Biol Med* 27:25–39.
- Bawin SM, Kazmarek KL, Adey WR (1975). Effects of modulated VHF fields on the central nervous system. *Ann NY Acad Sci* 247:74–81.
- Bawin SM, Adey WR, Sabbot IM (1978). Ionic factors in release of $^{45}\text{Ca}^{2+}$ from chicken cerebral tissue by electromagnetic fields. *Proc Natl Acad Sci USA* 75:6314–6318.
- Berk M, Dodd S, Henry M (2006). Do ambient electromagnetic fields affect behavior? A demonstration of the relationship between geomagnetic storm activity and suicide. *Bioelectromagnetics* 27:151–155.
- Blackman CF, Benane SG, Kinney LS, Joines WT, House DE (1982). Effects of ELF fields on calcium-ion efflux from brain tissue. *Radiat Res* 92:510–520.
- Cane HV (2000). Coronal mass ejections and Forbush decreases. *Space Sci Rev* 93:55–77.
- Clement B (2004). Dependence on the duration of geomagnetic polarity reversals on site latitude. *Nature* 248:637–640.
- Close J (2012). Are stress responses by geomagnetic storms mediated by the cryptochrome compass system. *Proc R Soc B*. doi: 10.1098/rspb.2012.0324.
- Commisso N, Del Giudice E, De Ninno A, Fleischmann M, Giuliani L, Mengoli G, Merlo F, Talpo G (2006). Dynamics of the ion cyclotron resonance effect on amino acids adsorbed at the interfaces. *Bioelectromagnetics* 27:16–25.
- Compton AH (1933). A geographic study of cosmic rays. *Phys Rev* 43:387–403.
- Corenellisen G, Halberg F, Breus T, Syutkina EV, Baevsky R, Weydahl A, Watanabe Y, et al. (2002). Non-photic solar associations of heart rate variability and myocardial infarction. *J Atmos Solar Terr Phys* 64: 707–720.
- Cossarizza A, Monti D, Bersani F, Paganelli R, Montagnani G, Cadossi R (1989). Extremely low frequency electromagnetic fields increase interleukin-2 (IL-2) utilization and IL-2 receptor expression in lymphocytes from old subjects. *FEBS Lett* 248:141–144.
- Crain IK (1971). Possible direct causal relation between geomagnetic reversals and biological extinctions. *GSA Bull* 82:2603–2606.
- Del Giudice E, Fleischmann M, Preparata G, Talpo G (2002). On the “unreasonable” effects of ELF magnetic fields upon a system of ions. *Bioelectromagnetics* 23:522–530.
- Dutta SK, Subramoniam A, Ghosh B, Parshard R (1984). Microwave radiation-induced calcium ion efflux from human neuroblastoma cells in culture. *Bioelectromagnetics* 5:71–78.
- Dutta SK, Ghosh B, Blackman CF (1989). Radiofrequency radiation-induced calcium ion efflux enhancement from human and other neuroblastoma cells in culture. *Bioelectromagnetics* 10: 197–202.

- Erren TC, Pape HG, Reiter RJ, Piekarski C (2008). Chronodisruption and cancer. *Naturwissenschaften* 95: 367–382.
- Fitzsimmons RJ, Ryaby JT, Magee FP, Baylink DJ (1995). Combined magnetic fields increase insulin-like growth factor-II in TE-85 human osteosarcoma bone cell cultures. *Endocrinology* 136:3100–3106.
- Gaetini R, Ledda M, Barile L, Chimenti I, De Carlo F, Forte E, Ionta V, et al. (2009). Differentiation of human adult cardiac stem cells exposed to extremely low-frequency electromagnetic elds. *Cardiovasc Res* 82:411–420.
- Galland P, Pazur A (2005). Magnetoreception in plants. *J Plant Res* 118:371–389.
- Greenebaum B, Barnes FS, editors (2006). Bioengineering and biophysical aspects of electromagnetic fields (handbook of biological effects of electromagnetic fields). 3rd ed. Boca Raton, FL: CRC Press.
- Hays JD (1971). Faunal extinctions and reversals of the earth's magnetic field. *GSA Bull* 82:2433–2447.
- Jenrow KA, Smith CH, Liboff AR (1995). Weak extremely-low-frequency magnetic fields and regeneration in the planarian *Dugesia tigrina*. *Bioelectromagnetics* 16:106–112.
- Kaye SM, Kivelson MG (1979). Observations of Pc 1-2 waves in the outer magnetosphere. *J Geophys Res* 84: 4267–4276.
- Kyker Jr, GC, Liboff AR (1978). Absolute cosmic ray ionization measurements in a 900-liter chamber. *J Geophys Res* 83:5539–5549.
- Liburdy RP, Sloma TR, Sokolic R, Yaswen P (1993). ELF magnetic fields, breast cancer, and melatonin: 60 Hz fields block melatonin's oncostatic action on ER + breast cancer cell proliferation. *J Pineal Res* 14:89–97.
- Liboff AR, Williams Jr, T, Strong DM, Wistar Jr, R (1984). Time-varying magnetic fields: effect on DNA synthesis. *Science* 223:818–820.
- Lopez DG (2012). Free radicals and cancer. Private communication.
- Love JJ (2008). Magnetic monitoring of earth and space. *Phys Today* 61:31–37.
- Okeke FN, Hamano Y (2000). Daily variations of H D and Z-field at equatorial latitudes. *Earth Planet Sci* 52: 237–243.
- Pazur A (2004). Characterisation of weak magnetic field effects in an aqueous glutamic acid solution by nonlinear dielectric spectroscopy and voltammetry. *Biomagn Res Technol* 2:8.
- Prato FS, Kavaliers M, Carson JJJ (1996). Behavioural Responses to Magnetic Fields by Land Snails are dependent on both magnetic field direction and light. *Proc R Soc Lond B* 263:1437–1442.
- Schwartz JL, House DE, Mealing GAR (1990). Exposure of frog hearts to CW or amplitude-modulated VHF fields: selective efflux of calcium ions. *Bioelectromagnetics* 11:349–358.
- Singer SF (1950). On the nature of the cosmic radiation near the Pfozter maximum at $\lambda = 41^\circ$ N. *Phys Rev Lett* 77:729–730.
- Smith SD, McLeod BR, Liboff AR, Cooksey K (1987). Calcium cyclotron resonance and diatom mobility. *Bioelectromagnetics* 8:215–227.
- Smith SD, McLeod BR, Liboff AR (1991). Effects of resonant magnetic fields on chick femoral development *in vitro*. *Electromagn Biol Med* 10:81–99.
- Timmel CR, Till U, Brocklehurst B, McLauchlan, Hore PT (1998). Effects of weak magnetic fields on free radical recombination reactions. *Mol Phys* 95:71–89.
- Wiltschko W, Wiltschko R (1972). Magnetic compass of European robins. *Science* 176:62–64.
- Wiltschko R, Wiltschko W (1985). Magnetic orientation in animals. Berlin: Springer-Verlag.
- Wrixon AD (2008). New ICRP recommendations. *J Radiol Prot* 28:161–168.
- Zhadin MN, Novikov VV, Barnes FS, Pergola NF (1998). Combined action of static and alternating magnetic fields on ionic current in aqueous glutamic acid solution. *Bioelectromagnetics* 19:41–45.
- Zhadin MN, Deryugina ON, Pisachenko TM (1999). Influence of combined DC and AC magnetic fields on rat behavior. *Bioelectromagnetics* 20:378–386.